OPTICAL RADAR BACKSCATTER MEASUREMENTS OF MOLECULAR DENSITY AND PARTICULATE MATTER IN THE MESOSPHERE AND LOWER THERMOSPHERE

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(This paper was presented by S. K. Poultney at the 1968 Annual Meeting of the American Geophysical Union)

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ABSTRACT

Recent optical radar backscatter measurements of molecular density and particulate matter in the mesosphere and lower thermosphere made at College Park, Md. and at Cloudcroft, New Mexico are reported and discussed. The potential of the Cloudcroft radar with respect to the time-scale, precision, and accuracy of molecular density measurements of the mesosphere is discussed to show that measurements with this radar are competitive in accuracy and resolution with meteorological rocket measurements. Alternate optical and optical radar techniques for these density measurements are also mentioned.

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I Experience with the Maryland Backscatter Optical Radar

Over the last three years[1,2,3,4], a backscatter optical radar has been developed and operated at the University of Maryland. Measurements of the molecular densities of the mesosphere and particulate matter concentrations at the mesopause have been obtained. Figure 4 shows a view of the radar. Figure 1 shows a schematic diagram of the equipment. The Maryland optical radar experience is unique in several ways. The same 20-inch telescope is used for both transmission and reception and an on-line computer is used to accumulate and process the digitized returns. The laser used is a Korad unit capable of providing 3 to 5 joules in a Q-chopped pulse twice a minute. The 20 nanosecond laser pulse is transmitted through a hole in the rotating disk. After the pulse has passed through the hole, the disk rotates to block all laser fluorescence and also to direct the backscatter into the detector. The digitized returns are collected in 2.5 km altitude bins by time-of-flight logic. A complete description of the radar and its operation is available[3,4]. This description includes detailed discussions of the myriad sources of noise that can contaminate the results of optical radar measurements. The shutter in front of the photomultiplier is especially important in eliminating a number of these sources of noise[2,3].

The results of measurements during August 1967 are shown in Figure 2. $\bar{E}$ is the average energy per firing, K is the number of firings, and $\bar{T}$ is the average atmospheric transmission. For molecular scattering, the differential backscattering function quoted is directly proportional to the density of the atmosphere at the altitude in question. Superimposed on the experimental data is the density of the relevant seasonal U. S. Standard Atmosphere (1962). The lower altitude limit is set by the special shutter which protects the photomultiplier tube from the initial light burst. The error bars (and upper altitude limit) clearly depend on the length of the observation period for a radar with a given output and sensitivity. The length of the observation period is the number of shots (K) divided by the laser repetition rate. A radar with a much higher repetition rate and an improved sensitivity is discussed below. In several of our publications, absolute densities are quoted. This accuracy has been obtained by careful calibration of our radar. We usually determine the atmospheric transmission by viewing Polaris. However, we have recently proposed an off-zenith backscatter method[4].

The structure appearing at about the mesopause is thought to be accumulations of aerosols. We have spent much time and effort making sure the echos are real. The higher scattering functions of these aerosols make it possible to monitor their density (or size) fluctuations on a considerably shorter time-scale than molecular density measurements of the same precision at the same altitude. Scattering functions of about 10^{-11} cm^{-1} are typical[5]. However, the mesopause concentrations are not always observed. For example, no mesopause accumulations were seen on 30 and 31 January 1967 whereas they were present on 4, 5, and 7 of February 1967. The excess backscatter from about 65 to 70 km is regularly observed. Work continues with the Maryland backscatter radar to correlate the appearance of mesopause accumulations with certain extra-terrestrial events.

II The Potentials of Backscatter Optical Radar for Mesosphere Density Measurements

In this talk, I want to emphasize mesosphere density measurements rather than mesopause particulate matter accumulations. The continued development of higher energy, higher repetition-rate lasers greatly enhances the potential of backscatter optical radar for mesosphere density measurements. For example, the Maryland group joined with the Air Force Electro-Optical Surveillance Site at Cloudcroft, New Mexico to gain experience using a 4 joule, one pulse per second, 1/4 milliradian beam divergence laser in conjunction with a 48 inch receiving telescope[6]. The potential of this backscatter radar will be discussed below. First, however, let us set up certain design criteria. Data presented in the 1962 U. S. Standard Atmosphere, the 1966 Supplement and by Quiroz[7] indicate that accuracies of 3 to 5% at 30 km decreasing to 8% at 80 km must be achievable with optical radar measurements for these to compare favorably with the other methods for determining absolute densities. Our goal is an accuracy of 5% at all altitudes of interest. (It is quite likely that one may willingly sacrifice some of this required accuracy for the capability of optical radar to make measurements nightly over a long period at a relatively modest cost.) Further discussions with R. Quiroz brought out that the height resolution should be about 1/2 km to match that of the other methods. Observation periods of not greater than two hours were considered adequate for meteorological time-scale changes.

The potential of the Cloudcraft backscatter radar is emphasized in Figure 3. The number of shots, K, and observation period needed to obtain a 5% precision with 95% confidence at each altitude interval is shown as a function of altitude. The curve was calculated from (1)

$$K = \frac{4}{f^2} \frac{N_m(z) + N_n}{N_m^2(z)} \tag{1}$$

$N_m(z)$ is the number of counts detected per 0.5 Km interval per shot from the altitude z. N_n is the limiting count/interval/shot determined by dark current, fluorescence noise, or sky noise; whichever dominates. The parameter αQ is a measure of the sensitivity of the receiver. Thus, the Cloudcraft radar can determine mesosphere molecular densities to 5% (in the absence of aerosols) up to 75 Km with a 1/2 Km height resolution within the desired two hour period. The observation periods for all lower heights are less than two hours. Such a potential certainly makes backscatter radar measurements competitive with rocket measurements; at least up to 75 Km. Above that height, other methods must be used.

The present Maryland backscatter radar is also shown on Figure 3. It is evident that the Maryland radar is only useful for long period, low resolution density measurements, and the monitoring of particulate matter accumulations at the mesopause. In the latter measurements, a height interval of 2.5 Km is used and returns ten times molecular Rayleigh scattering are expected so that 20% measurements within several hours are achievable.

III Other Optical Radar Topics

A. Improvements in Present Backscatter Optical Radars

The optimum backscatter optical radar would transmit the largest amount of energy within a time corresponding to the height resolution. However, many backscatter radars use a Q-switch device that yields a several joule pulse about twenty nanoseconds long. Power damage thresholds prevent a significant increase in energy of the short pulse. One means to approach the optimum pulse is now being tried at Maryland. This method consists of stretching the pulse by introducing a non-linear limiter in the laser cavity[8] and thereby being able to raise the pulse energy without damage problems. This method should also reduce the near-field hotspots which damage the transmitting optics.

B. Mesosphere Temperatures

The determination of temperature profiles from density profiles is a standard procedure (e.g. R. Craig, "The Upper Atmosphere", p. 60, Academic Press, 1965). Typically, one loses a scale height or two depending on the uncertainty of the temperature of an upper reference level.

C. Investigation of the Nature of the Particulate Matter at the Mesopause

An investigation of the nature of the particulate matter at the mesopause is being considered in collaboration with Dr. H. Plotkin of Goddard Space Flight Center. A GSFC optical radar transmitter at Wallops Island would allow the detection at the University of Maryland of light scattered 90^{o} from a particulate matter accumulation at the mesopause.

Polarization studies of the scattered light might then reveal something about the particle size and/or shape; particularly whether or not the particles are Rayleigh scatterers (i.e. diameters < 1 μ).

D. Applications of the Properties of Coherent Light Scattered from Rough Targets

The temporal coherence of lasers has made possible a number of spectral investigations of molecular[9] and particle velocities[10,11]. However, very little direct use has yet been made of the spatial coherence of lasers for such purposes. One group of workers[11] has been able to verify the Mie scattering formula and measure the velocities of particles in Brownian motion using the properties of spatially coherent light. Goodman[12] has considered the detection statistics of coherent light reflected from rough, stationary targets. It now appears[13] that, using the method of detection statistics with a pulsed optical radar, one could determine both particle range and characteristic velocity.

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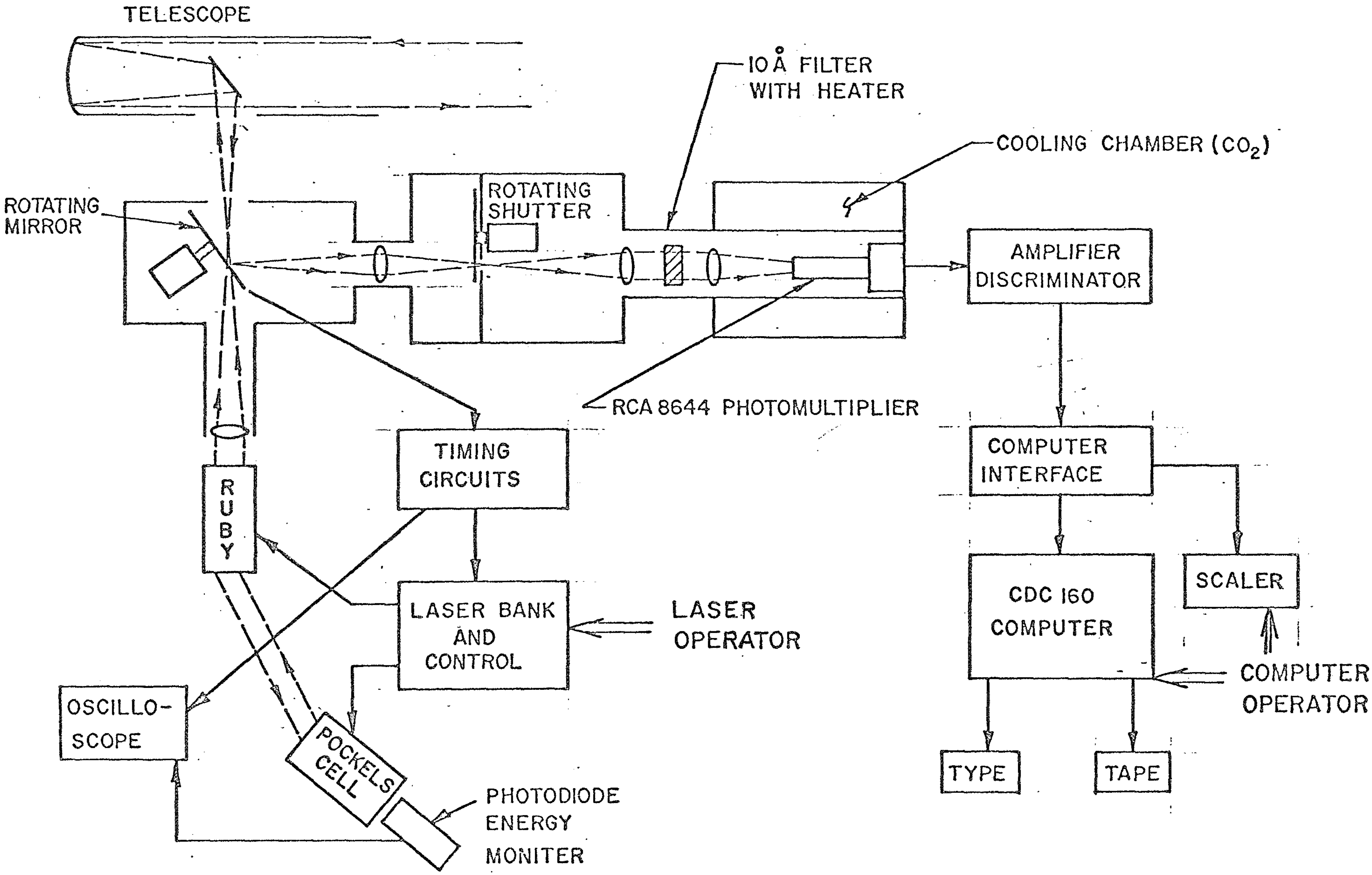


Fig. 1 OPTICAL RADAR BLOCK DIAGRAM.

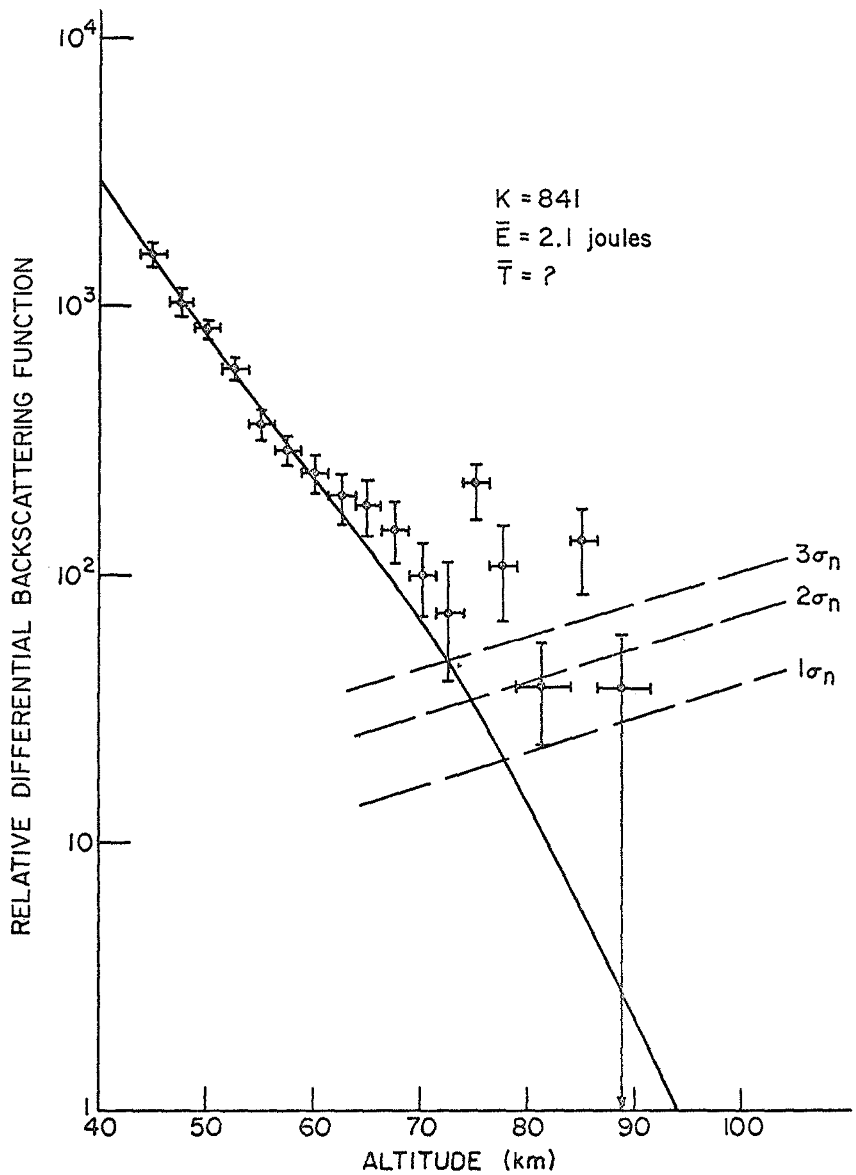
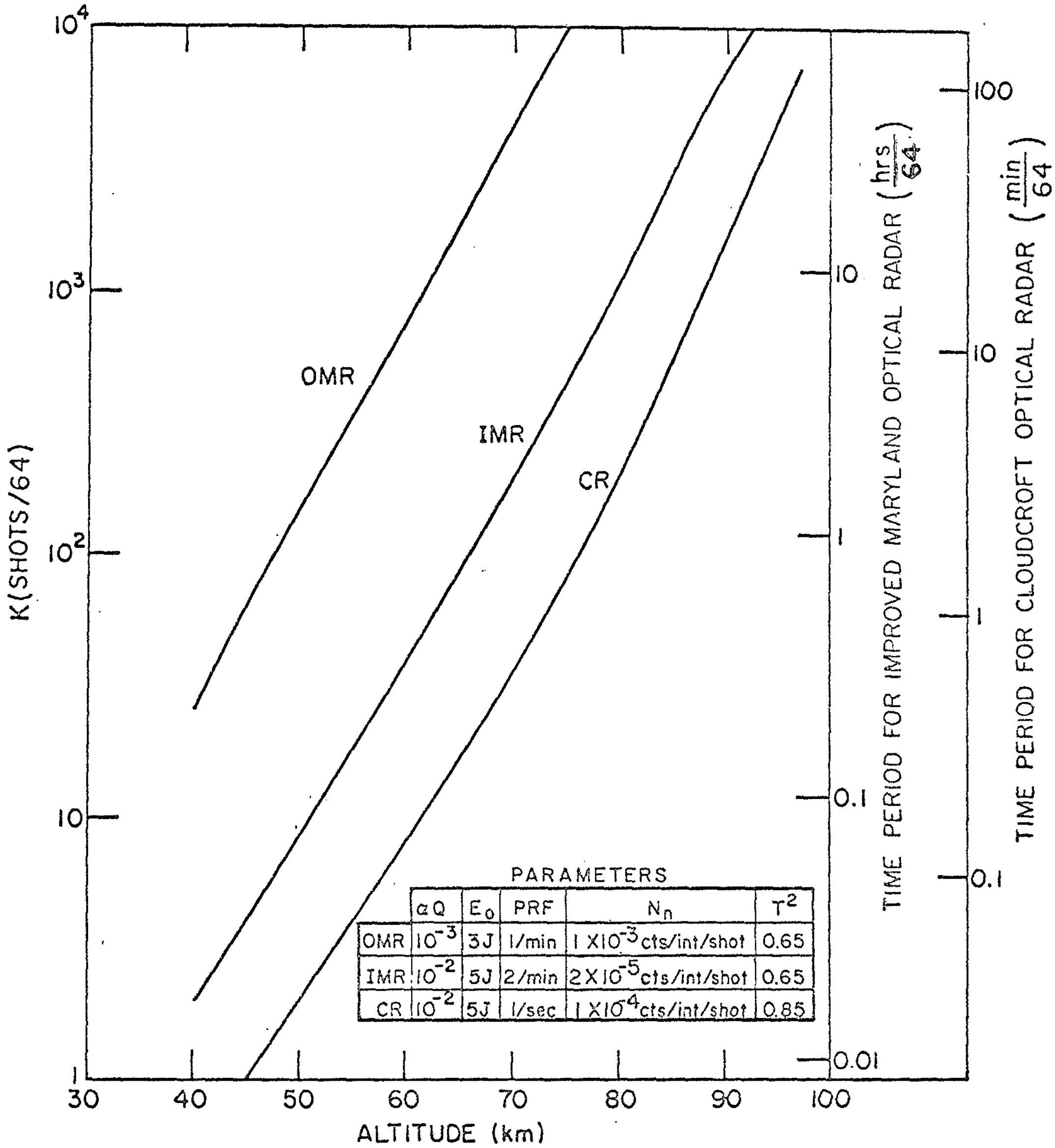


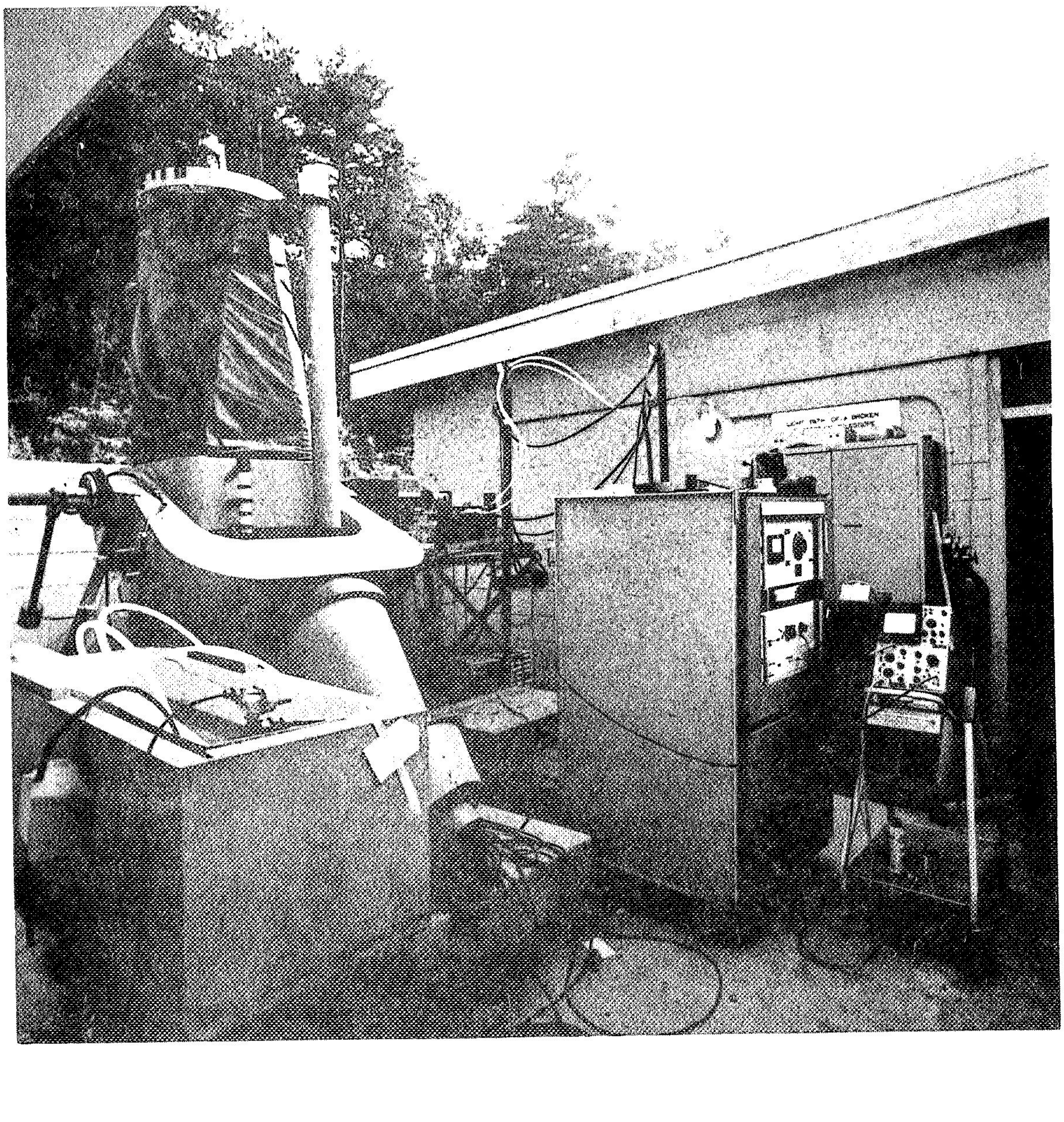
Fig. 2 RELATIVE DIFFERENTIAL BACKSCATTERING FUNCTION FOR 1, 7, 8, 9, 14, 15, AUG. 1967, COLLEGE PARK, MARYLAND.



PARAMETERS

	αQ	E_0	PRF	N_n	T^2
OMR	10^{-3}	3J	1/min	1×10^{-3} cts/int/shot	0.65
IMR	10^{-2}	5J	2/min	2×10^{-5} cts/int/shot	0.65
CR	10^{-2}	5J	1/sec	1×10^{-4} cts/int/shot	0.85

Fig. 3 NUMBER OF SHOTS NEEDED TO MEASURE MOLECULAR SCATTERING TO A PRECISION OF 5% WITH THE ORIGINAL MARYLAND RADAR, THE IMPROVED MARYLAND RADAR, AND THE CLOUDCROFT RADAR. (HEIGHT RESOLUTION: 0.5 km)



PHOTOGRAPH A